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Assessment of Physico-Chemical Properties of Biogas Slurry as an Organic Fertilizer for Sustainable Agriculture

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ABSTRACT

Chemical fertilizers have been extensively used for growing crops and controlling plant diseases, but they pose potential hazards to the environment, soil health, plants, and people. The current world situation highlights the need to implement eco-friendly agricultural practices for sustainable crop production. Using environmentally friendly manure, such as biogas slurry, can help reduce the negative effects of chemical fertilizers. Biogas slurry is an efficient waste material and organic fertilizer, making it an ideal supplement for sustainable crop production and waste management. An experiment was conducted at IARI, New Delhi, to explore the nutrient potential of biogas slurry. The main objective of this study was to assess biogas slurry's physico-chemical characteristics and nutrient contents. Samples of biogas slurry were collected in three replications and analyzed using standard methods for macro and micronutrients. The data revealed that biogas slurry has a pH of 7.2-8.5, EC of 1.06 to 1.12 dS/m, and organic carbon content of 41.7 to 45.8%. In terms of fertility, it contains significant amounts of nitrogen (1.98-2.17%), phosphorus (0.97 to 1.15%), and potassium (1.98 to 2.17%). Additionally, biogas slurry contains micronutrients such as Zn (0.023-0.027 ppm), Cu (0.005-0.009 ppm), Fe (0.32-0.38 ppm), and Mn (0.089-0.094 ppm). Statistical analysis using ANOVA and Post Hoc tests indicated that the mean data values among all three replications do not differ significantly. Therefore, it can be concluded that the nutritive value of biogas slurry is sufficient to reduce the reliance on chemical fertilizers in agriculture. It represents an optimal long-term organic remedy for developing fertile soil, ensuring enduring agricultural productivity, and mitigating the negative environmental impacts associated with waste management.

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1 Introduction

The agriculture sector plays a significant role in India's economy and significantly impacts the country's GDP. According to the Food and Agriculture Organization (FAO), there is projected to be a 60% increase in the demand for agricultural commodities by 2030, with over 85% of this increase attributed to developing economies (Mia and Shamsuddin 2010). The use of chemical fertilizers has increased globally, leading to higher farm productivity but also posing environmental challenges (Faheed and Abd-El Fattah 2008; Thorat and More 2022). In India, the use of chemical fertilizers significantly rose in the 1960s following the introduction of high-yielding crop varieties. However, the excessive use of chemical fertilizers can lead to soil degradation, such as acidification and reduced fertility, impacting crop yields over time (Yadav et al. 2023).

Nitrogen (N) fertilizers are the main source of N_2O emissions from agricultural soil, with the agricultural sector contributing 65–80% of the world's N_2O emissions (Ghosh et al. 2022; Mosier and Kroeze 2000; IPCC 2007). Overusing nitrogen-based fertilizers can lead to nitrate leaching, contaminating groundwater and causing adverse effects on the ecosystem (Sharma et al. 2022). This can result in nitrate and phosphate runoff from agricultural fields, leading to eutrophication in nearby water bodies, harming fish populations and posing health risks to humans and animals (Agarwal et al. 2010; Rahman et al. 2008).

Inorganic fertilizers contain poisonous elements that plants absorb, pass through to vegetables and grains, and enter the food chain. This can result in financial losses and environmental harm (Tirado and Allsopp 2012). Fertilizers include various heavy metals such as lead, mercury, uranium, and cadmium, which can severely damage the kidneys, lungs, and liver and, at higher concentrations, can be a cause of cancer (WHO 1992). A higher dose of potassium may cause kidney dysfunction, diabetes, hypertension, heart disease, coronary artery disease, adrenal insufficiency, and pre-existing hyperkalemia (APHA 1998). Cadmium toxicity, known as "Itai-Itai", was first identified in Japan in 1912. When associated with human tissues, cadmium may cause harm, especially to kidneys, bones, and lungs. Therefore, if chemical fertilizer is not handled properly, it can put farmers at risk for poisoning, and straw made from crops fertilized with chemical fertilizer can cause animals to grow thin (Berihu 2012).

The shift towards environmentally sustainable practices is crucial, moving away from conventional methods and prioritizing organic farming over chemical fertilizers to improve soil quality and ecological well-being. Organic farming differs significantly from chemical fertilizers by reducing nutrient loss, enhancing soil fertility (Gattinger et al. 2012), lowering global warming potential (Cavigelli et al. 2013), and increasing crop yields (Seufert et al. 2012). Organic residues are key to soil fertility (Ayuso et al. 1996). While inorganic fertilizers contain higher levels of plant nutrients than organic fertilizers, including organic fertilizers is essential for improving soil fertility and agricultural productivity (Sanwal et al. 2007; Adeleye et al. 2010). Organic agriculture, a sustainable farming method, has gained global interest, but specific challenges must be addressed to expand these practices (Kumar et al. 2023). The utilization of organic residues, especially biogas slurry (BGS), may provide a potential solution (Malav et al. 2015) and serve as a viable alternative to synthetic fertilizers for ecologically sustainable agricultural practices (Tang et al. 2022).

Anaerobic digestion of crop residues and animal manure produces biogas slurry, often used as a substitute to reduce mineral fertilizer input (Sun et al. 2024). Cow dung (CD) is commonly used as a feedstock for biogas production and a source of BGS (Younessi et al. 2023). The discharge of biosolids (BS) currently presents significant environmental challenges. Therefore, it is crucial to explore alternative strategies for the effective utilization of biosolids (Wang et al. 2023). Biogas slurry, a byproduct of the anaerobic digestion of livestock manure, is a highly efficient method for the management and disposal of livestock manure and agricultural byproducts (Kang et al. 2020; Ferdous et al. 2020; Liang et al. 2023; He et al. 2024). It contains significant nutrients compared to other organic manures, such as farmyard manure (FYM) and composts (Table 1). Due to its high nutrient content, the use of biogas slurry as a fertilizer has significantly increased in China and many other Asian nations (Gupta et al. 2016). In India, the generation of biogas slurry has increased, leading to significant environmental disposal issues (Khan et al. 2015).

Table 1 Nutritional comparison of biogas slurry and other compost

Slurry	Oven-dried slurry	Slurry compost	Biogas effluent	Ordinary compost	Biogas sludge	Farmyard manure (FYM)
Nitrogen %	1.6 - 3.7	0.57 - 2.23	0.03 - 0.08	0.5 - 1.0	0.8 - 1.5	0.3 - 0.5
Phosphorus %	1.6 - 2.2	0.072 - 2.11	0.02 - 0.06	0.1 - 0.3	0.4 - 0.6	0.1 - 0.2
Potassium %	0.8 - 3.6	0.0 - 5.1	0.5 - 0.10	0.5 - 0.7	0.6 - 0.12	0.5 - 0.7
References	Karki 2004	Vaidya et al. 2007	Warnars and Oppenoorth 2014	Meena and Biswas 2013	Yakout et al. 2014	Bandyopadhyay et al. 2010

(Source: Mukhtiar et al.2024)

The government of India has recently implemented substantial measures to promote the utilization of biogas slurry as an organic fertilizer. The livestock population in India is estimated to be 512.05 million (Dikshit and Pratap 2010). Each year, 76.8 million tons of slurry and approximately 1.15 metric tons of nitrogen are produced in India (Kumar et al. 2015). It has been estimated that using slurry instead of chemical fertilizer can reduce nitrogen use by around 8.78%, phosphorus use by about 11.01%, and potassium use consumption by roughly 14% (Devarenjan et al. 2019). By using biogas slurry, farmers can lower their production costs and increase soil fertility and productivity while reducing the use of chemical fertilizers.

Biogas slurry is a product of the anaerobic digestion of organic material, primarily used for cooking, lighting, and running machinery (Kamp and Forn 2016). It is a low-cost, environmentally friendly, and safe option for people and animals (Islam et al. 2016). According to Devarenjan et al. (2019), biogas slurry consists of 93 percent water, 4.50 percent dry matter, and 2.50 percent inorganic matter. It contains significant levels of macronutrients (N, P, K) and micronutrients (Zn, Mn, B) essential for plant growth, making it a valuable source of organic fertilizer (Alam 2006). The biogas slurry contains 1.50 percent nitrogen, 1.10 percent phosphorus, and 1.0 percent potassium. Additionally, Vinh (2010) suggested that one cubic meter of biogas slurry contains 0.16 to 1.05 kg of nitrogen, equivalent to 0.35 to 2.5 kg of urea. The growth rate of crops can be significantly improved by using biogas slurry (Ahmad and Jabeen 2009) and enhancing the nutrient content in crops (Vishwakarma et al. 2023). Most research has shown that using biogas slurry resulted in maximum crop yields. For example, the anaerobic digestate from beef cows increased nitrogen and phosphorus intake in barley fodder (Tang et al. 2021). Jothi et al. (2023) also found a significant enhancement in tomato yield and the number of fruits produced per plant when they utilized biogas slurry obtained through an anaerobic digestion process. Similarly, optimal rice and rapeseed production levels were achieved by applying biogas slurry at 165.10 and 182.10 t ha^{-1} (Zhang et al. 2022). Garg et al. (2005) reported an increase in maize grain yields (6.21 Mg ha^{-1}) and an enhancement of root length density (1.10 cm cm^{-3}) by using biogas slurry at the rate of 15 Mg ha^{-1}. Kumar et al. (2015) and Feng et al. (2024) reported that biogas slurry can reduce chemical fertilizer use by 15% to 20%. These studies suggest that the efficient use of organic fertilizers promotes economic development, improves agricultural sustainability, and positively affects the environment by reducing reliance on imported chemical fertilizers. This information was gathered during a study conducted at the Indian Agricultural Research Institute (IARI), New Delhi, to explore the benefits of biogas slurry in agriculture and to estimate its physico-chemical characteristics and nutrient contents.

2 Materials and Methods

2.1 Biogas sample collection, preparation and analysis

The experiment occurred at CESCRA, ICAR-Indian Agricultural Research Institute (IARI) in New Delhi, India. Biogas slurry samples were collected from biogas plants at the IFS Agronomy Division of IARI farm in New Delhi. The collected samples, with a volume of 1 L and containing between 92 and 93% water content, underwent a 15-day sun-drying process. After drying, the samples were crushed and sieved through a 2 mm sieve (Figure 1). Subsequently, the biogas slurry was analyzed at the Laboratory of CESCRA, ICAR-IARI, in New Delhi to determine various parameters using standard methods (Table 2).

The biogas slurry samples were analyzed for their physicochemical parameters. Each analysis was conducted in three replications. To determine the total solids content in the biogas slurry, the samples were subjected to oven drying at 105°C until a consistent weight was achieved, and then the weight of the dried residue was calculated. The pH and electrical conductivity are important for characterizing biogas slurry, so they were measured in fresh samples using a pH meter and an electrical conductivity meter.

Figure 1 Biogas slurry sample collection and preparation

Table 2 Physico-chemical parameters and their estimation methods

Parameter	Methods
Soil pH (1:2.5 soil: water)	Piper1966
Electrical conductivity (dS/m)	Jackson1967
Organic carbon (%)	Walkley and Black1934
Nitrogen (%)	Kjeldahl 1883
Phosphorus (%)	Vanado molybdate phosphoric yellow colour method, Jackson 1973
Potassium (%)	Flame photometer method, Jackson 1973
Micronutrients (Zinc, Copper, Iron and Manganese)	Lindsay and Norvell 1978

Table 3 Physico-chemical characterization of biogas slurry

Nutrient content in biogas slurry				
Parameters	Total solids (%)			
Range	5.2-6.5			
Average ± Stand. dev.	5.83±0.651			
Parameters	pH	Electric conductivity (dS/m)	Organic Carbon (%)	
Range	7.2-8.5	1.06-1.12	41.7-45.8	
Average ± Stand. dev.	7.80 ±0.656	1.09 ±0.030	43.80 ±2.052	
Macronutrients (%)				
Parameters	Nitrogen	Phosphorus	Potassium	
Range	1.98-2.17	0.99-1.15	0.91-1.16	
Average ± Stand. dev.	2.09 ± 0.100	1.07 ± 0.091	1.03 ± 0.126	
Micronutrients (ppm)				
Parameters	Zinc	Copper	Iron	Manganese
Range	0.023-0.027	0.005-0.009	0.32-0.38	0.089-0.094
Average ± Stand. dev.	0.03 ±0.002	0.01 ±0.002	0.36±0.032	0.09 ±0.003

2.2 Statistical analysis

The data obtained from three replications of biogas slurry were analyzed using statistical methods. The statistical technique used for this analysis was an analysis of variance (ANOVA) and a Post Hoc test. These tests were used to identify any significant differences between the means of the three replications (Zheng et al. 2017; Xu et al. 2021). In this study, each parameter represents a dependent group, and the replications of biogas slurry (R-I, R-II, R-III) are the independent groups. The Null Hypothesis (H_0) in the analysis of variance states that the means of the total composition of biogas slurry for the three replications are equal, while the Alternative Hypothesis (H1) states that at least one of the means is different among all the replications.

3 Results and Discussion

3.1 Physico-chemical characteristics of biogas slurry

The biogas slurry samples were collected and taken to the laboratory for analysis. The nutrient components of biogas slurry can vary depending on factors such as the constituents of the feedstock, efficiency of the digestion process, any additives or treatments used, etc. The physico-chemical factors that determine whether biogas slurry is suitable to use as manure for crops include total solids, pH, electrical conductivity, organic carbon, nitrogen, phosphorus, potassium, and micronutrients (such as Zn, Cu, Fe, and Mn). Three replications of biogas slurry have been analyzed for their physico-chemical properties (Table 3).

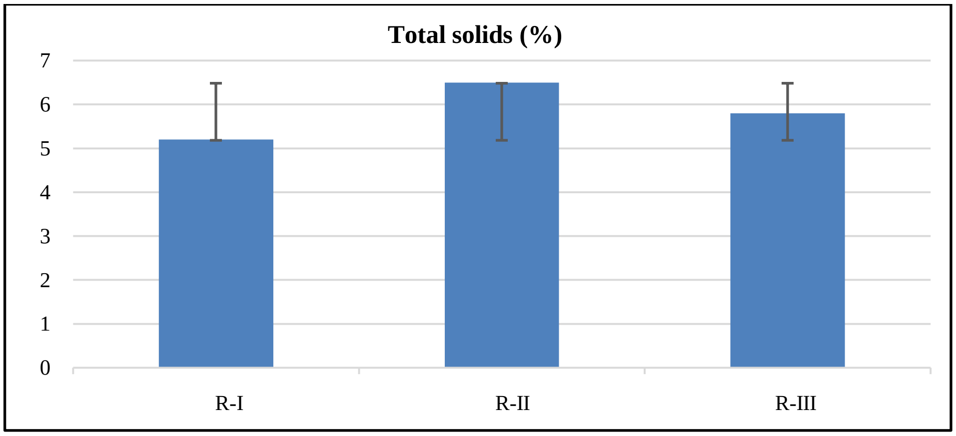

Figure 2 Total solids in the current biogas slurry sample

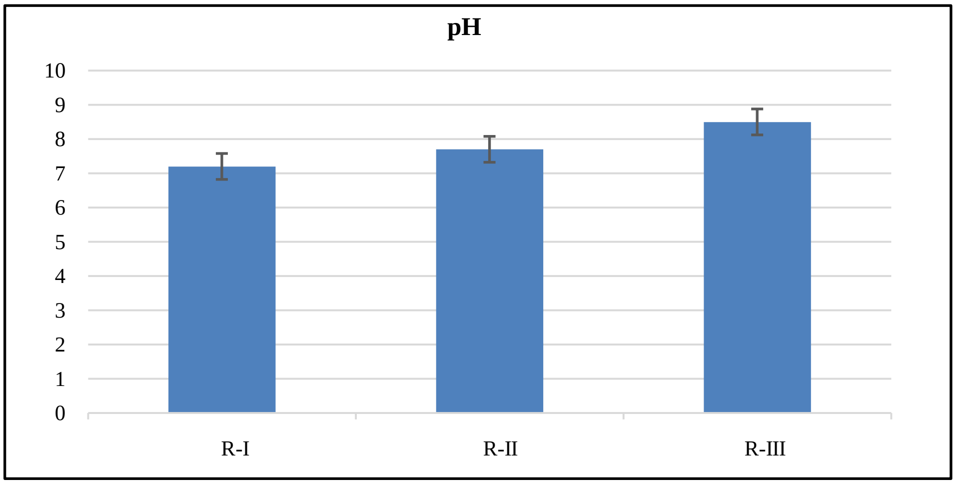

Figure 3 pH in biogas slurry

3.1.1 Total solids

The amount of solid materials present in biogas slurry can vary depending on the specific sample and the type of feedstock used in biogas production and digestion. According to the current study, the total solids content ranges from 5.2 to 6.5 percent (Figure 2). These findings are consistent with the results reported by Barasa et al. (2020), who indicated that a total solids concentration of 6 to 8 percent is beneficial for stabilizing anaerobic digestion processes. Research on biogas production from bovine excreta has explored a wide range of dilutions (2:1–1:19) and associated total solids concentrations (ranging from 1% to 13.5%), as well as extremely low total solids levels (TS < 4%) (Jeppu et al. 2022).

3.1.2 pH and Electric conductivity

Monitoring and controlling the pH of biogas slurry is crucial to maintaining optimal conditions for the microbial activity responsible for biogas production. However, this range can fluctuate due to the specific conditions of the biogas reactor and the quality of the feedstock being processed. The pH level in the soil directly impacts the availability of the nutrients required for plant growth. The data related to pH monitoring revealed that the pH of the biogas slurry ranges from 7.2 to 8.5 (Figure 3). These results are consistent with earlier findings that the pH value of biogas slurry falls within the range of 7.69 to 8.29 (Malav et al. 2015; Naihui et al. 2023). Studies have indicated that different pH levels can influence biogas production from bovine excreta, with a pH of about 8.52, resulting in an alkaline condition (Bahira et al. 2018). Additionally, biogas slurry can neutralize acidic soils and improve soil pH (Feng et al. 2024).

It is crucial to regularly monitor and manage the electrical conductivity to maintain the stability and efficiency of biogas production processes. The biogas slurry's electric conductivity (EC) ranged from 1.06 to 1.12 dS/m, as shown in Figure 4. The concentration of electric conductivity is dependent on the concentrations of dissolved ions and salts. In a previous experiment, Yadav et al. (2023) demonstrated that the electric conductivity of biogas slurry ranged between 1.72 and 1.83.

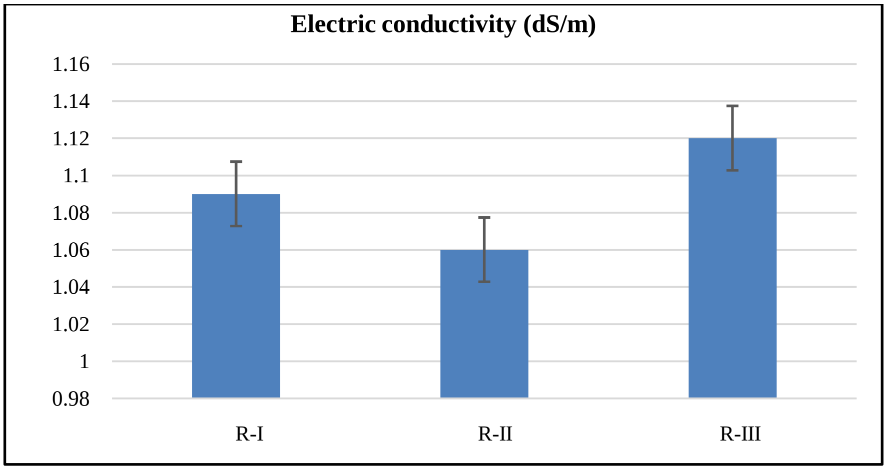

Figure 4 Electric conductivity in biogas slurry

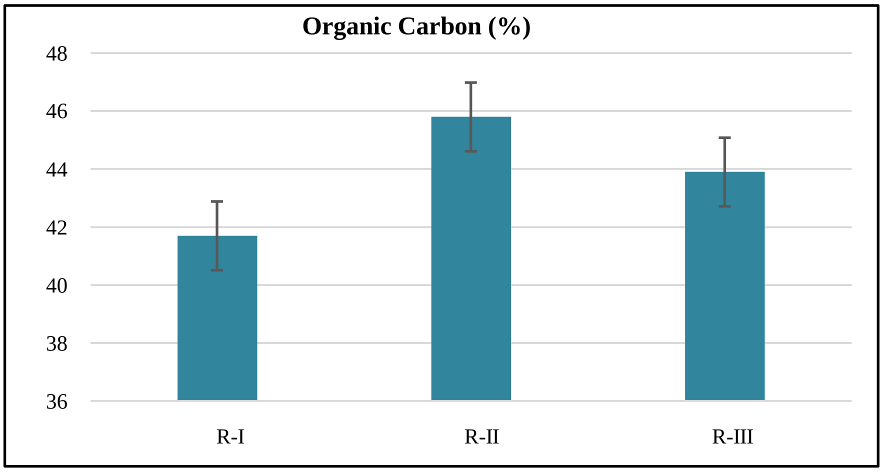

Figure 5 Organic carbon in biogas slurry

3.1.3 Organic carbon

The biogas slurry samples were analyzed for their organic carbon content, crucial for determining their nutrient value and potential use as a nutrient-rich fertilizer for agriculture or soil improvement. The study showed that the biogas slurry contains approximately 41.7 to 45.8 percent organic carbon (Figure 5). Biogas slurry (BS) is widely acknowledged as a significant source of organic matter and essential nutrients for enriching soil organic carbon (Chen et al. 2024).

The organic carbon in biogas slurry is crucial for maintaining microorganism stability, which in turn sustains continuous decomposition activity and enhances the nutritional dynamics of the digestate.

3.1.4 Nitrogen, Phosphorus and potassium (NPK)

The anaerobic breakdown of cow excrement leads to elevated levels of ammonium nitrogen while also increasing the durability of organic compounds. However, this process also significantly reduces the carbon-nitrogen ratio, leading to a higher presence of Nitrogen (Gutser et al. 2005). Given the high costs associated with phosphorus and potassium, which are important environmental concerns, using bio-slurry as an alternative source is expected to reduce agricultural production costs substantially. Data shows that biogas slurry's nitrogen, phosphorus, and potassium content ranges from 1.98 to 2.17 percent, 0.97 to 1.15 percent, and 0.91 to 1.16 percent, respectively (Figure 6). With its NPK content, biogas slurry can be used as a nutrient-rich organic fertilizer due to its three essential nutrients for plant growth. The current study indicates slightly higher NPK values than those of Skrzypczak et al. (2023), who reported approximately 2.55 percent nitrogen, 0.57 percent phosphorus, and 1.77 percent potassium. Some research findings suggest that the combined use of liquid bio-slurry (20.6 mha^{-1}) and nitrogen (41 kg N ha^{-1}) has the potential to improve the physico-chemical characteristics of soil (Musse et al. 2020). This study is supported by research indicating that biogas slurry has a higher NPK content than chemical fertilizers (Vishwakarma et al. 2023).

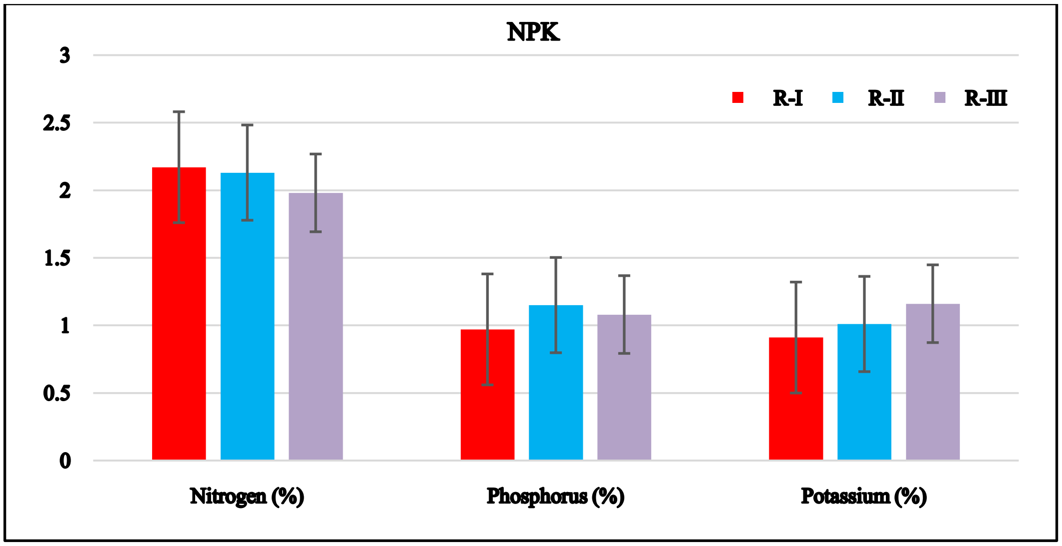

Figure 6 NPK in biogas slurry

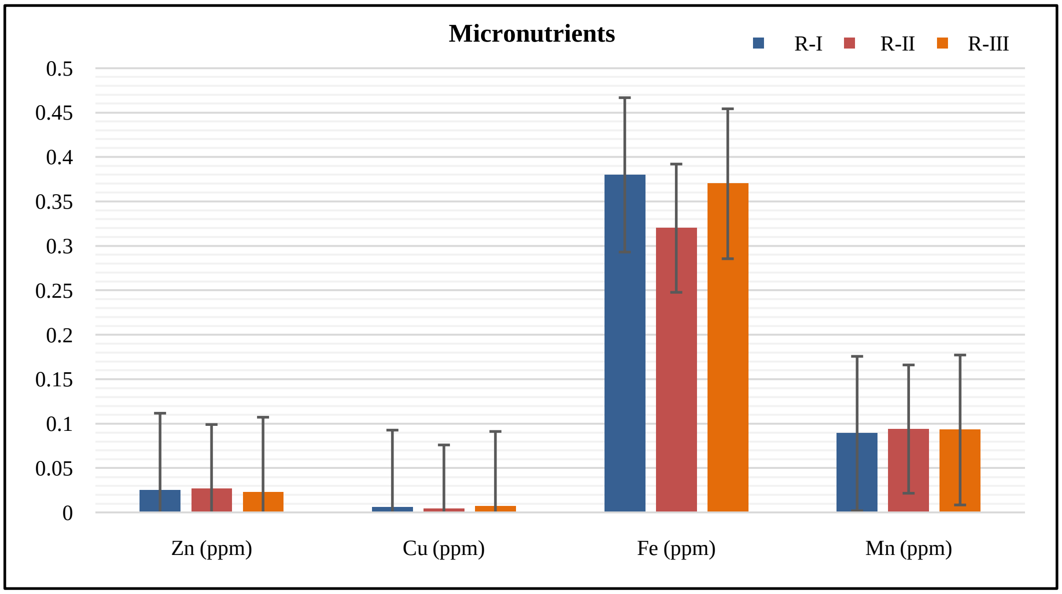

Figure 7 Micronutrients in biogas slurry

3.1.5 Micronutrients

Plant growth is heavily dependent on micronutrients. Plants require a precise balance of essential nutrients for optimal development and productivity. As a result, the micronutrient content in biogas slurry has been analyzed using AAS. The study data revealed that the micronutrients zinc, copper, iron, and manganese range from 0.023-0.027 ppm, 0.005-0.009 ppm, 0.32-0.38 ppm, and 0.089-0.094 ppm, respectively (Figure 7). Previous research has also confirmed that biogas slurry provides a rich supply of micronutrients essential for plant growth, including Zn, Cu, Fe, and Mn (Liu et al. 2023). Malav et al. (2015) reported that biogas slurry contains Zn (0.023 ppm), Cu (0.004 ppm), Fe (0.34 ppm), and Mn (0.088 ppm). Therefore, the results of the current study are consistent with those of these researchers.

3.2 Statistical analysis

3.2.1 Analysis of variance (ANOVA) among three replications of biogas slurry

The results from the physicochemical analysis of three sets of biogas slurry were statistically interpreted using the ANOVA method. This statistical approach will help identify significant differences in the parameter means across all three sets (Table 4). The P value was greater than 0.05, indicating no significant

Table 4 ANOVA test among three replications of biogas slurry

	Sum of the squares	df	Mean of the square	F	Sig.
Between the Groups	1.770	2	0.885	0.005	0.995
Within the Groups	4983.173	30	166.106		
Total	4984.943	32			

Table 5 Post Hoc Tests among three replications of biogas slurry

Replications		Mean Differences (I-J)	Standard Errors	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
R-I	R-II	-0.551364	5.495548	0.994	-14.09938	12.99665
	R-III	-0.391182	5.495548	0.997	-13.93920	13.15684
R-II	R-I	0.551364	5.495548	0.994	-12.99665	14.09938
	R-III	0.160182	5.495548	1.000	-13.38784	13.70820
R-III	R-I	0.391182	5.495548	0.997	-13.15684	13.93920
	R-III	-0.160182	5.495548	1.000	-13.70820	13.38784

difference between all three replications of biogas slurry. The composition of parameters in each replication is equally impacted. This study demonstrates that there is no significant difference among the replications.

3.2.2 Comparison of replications of biogas slurry through Post Hoc Test

The data from all three replications were analyzed using a post hoc test to gain a better understanding of the differences among them. This test is done after an ANOVA to compare the means of the different replications and identify where the significant differences are. After comparing the treatment replications, it was found that there were no significant differences among the different replications of biogas slurry (Table 5).

In this experiment, the biogas slurry was considered the dependent variable, while the nutrients in the biogas slurry were treated as the independent variable. The null hypothesis (H_0) suggests no significant difference between the means of the replications, whereas the alternative hypothesis (H_1) indicates that the means of at least one replication significantly differ from the others. The means of the three biogas slurry replications do not vary significantly, as indicated by a P value greater than 0.05. The correlations among pH, electric conductivity, organic carbon, nitrogen, phosphorus, potassium, and micronutrients were positive and statistically significant. The results of this investigation suggest that biogas slurry has the potential to be an effective soil amendment compared to cow dung, as it can regulate soil pH, enhance nutrient accessibility, and gradually release phosphorus fertilizer according to specific plant requirements. The nutrients in the biogas slurry were statistically insignificant (>0.05), indicating that biogas slurry is a superior organic fertilizer for soil amendment compared to other organic fertilizers. In addition to significant amounts of organic matter, the biogas slurry under investigation contains sufficient macro and micronutrients crucial for plant development.

Conclusion

The study of biogas slurry in three replications showed that this organic manure contains a significant amount of macro and micronutrients. Statistical techniques such as ANOVA and Post Hoc tests were used to validate these results. The results indicated no significant difference in the mean values of any physico-chemical parameters of the biogas slurry between the three replications, with a P value larger than 0.05. This suggests that biogas slurry can provide enough nutrients to reduce India's reliance on chemical fertilizers, which benefits the country's economy and ecology. Farmers are encouraged to incorporate biogas slurry into their agricultural practices for environmentally friendly crop development and sustained crop growth.

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Conflict of Interest

Authors have no conflicts of interest.

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